DACA42-03-C-0024

LOGANEnergy Corp.

Residence of Lieutenant Colonel Jeffrey Jackson PEM Demonstration Program
Shaw Air Force Base, Sumter, South Carolina
Final Report

Proton Exchange Membrane (PEM) Fuel Cell Demonstration
Of Domestically Produced PEM Fuel Cells in Military Facilities

US Army Corps of Engineers
Engineer Research and Development Center
Construction Engineering Research Laboratory
Broad Agency Announcement CERL-BAA-FY02

Shaw Air Force Base
Sumter, South Carolina

November, 2004

Executive Summary

LOGANEnergy Corporation has received a contract award from the US Army Corps of Engineers, Construction Engineering Research Lab to test and evaluate Proton Exchange Membrane (PEM) Fuel Cells at several DOD sites. Shaw Air Force Base in Sumter South Carolina is one of the sites awarded to LOGAN. The main purpose of this program was to demonstrate the feasibility of obtaining a minimum of 90% availability over a one year period using a residential PEM fuel cell. The initial start-up of this PEM demonstration site occurred on April 30, 2003.

The personal residence of Lieutenant Colonel Jeffrey Jackson, commander of the Shaw AFB Civil Engineering Squadron was chosen for the demonstration site. It hosts a 5kW, 120vac, SU-1 PEM technology demonstration unit manufactured by Plug Power Corporation, Latham, New York. The unit operates in a grid parallel / grid synchronized configuration at 2.5kW and is capable of operating in a grid independent/load following configuration in the event of a power failure. The unit is instrumented with an external wattmeter, an ambient air sensor, a gas flow meter, a Btu meter and an Ultralite data logger to capture and record operating data. A phone line is connected to the power plant communication's modem to call-out with alarms or events requiring service and attention.

The Point of Contact for this project is Greg Skaggs, Shaw Utilities Engineer, (803) 895-9600. The total estimated energy cost increase to the host site as a result of participating in this demonstration project is $716.77.

Table of Contents

Proposal – Proton Exchange Membrane (PEM) Fuel Cell Demonstration of Domestically Produced Residential PEM Fuel Cells in Military Facilities

1.0 Descriptive Title

Residence of Lieutenant Colonel Jeffery Jackson, Shaw Air Force Base, Sumter, South Carolina, PEM Demonstration Program

2.0 Name, Address and Related Company Information

LOGANEnergy Corporation
1080 Holcomb Bridge Road
BLDG 100- 175
Roswell, GA 30076

(770) 650- 6388

Data Universal Numbering System (DUNS) Number: 01-562-6211
Commercial and Government Entity (CAGE) Code: 09QC3
Taxpayer Identification Number (TIN): 58-2292769

LOGANEnergy Corporation is a private Fuel Cell Energy Services company founded in 1994. LOGAN specializes in planning, developing, and maintaining fuel cell projects. In addition, the company works closely with manufacturers to implement their product commercialization strategies. Over the past decade, LOGAN has analyzed hundreds of fuel cell applications. The company has acquired technical skills and expertise by designing, installing and operating over 30 commercial and small-scale fuel cell projects totaling over 7 megawatts of power. These services have been provided to the Department of Defense, fuel cell manufacturers, utilities, and other commercial customers. Presently, LOGAN supports 30 PAFC and PEM fuel cell projects at 21 locations in 12 states, and has agreements to install 22 new projects in the US and the UK over the next 18 months.

3.0 Production Capability of the Manufacturer

Plug Power manufactures a line of PEM fuel cell products at its production facility in Latham, NY. This facility, which opened in February 2000, is comprised of 50,000 square feet of dedicated production and production test facilities. The facility produces three lines of PEM products including the 5kW GenSys5C natural gas unit, the GenSys5P LP Gas unit, and the GenCor 5kW standby power system. The current facility has the capability of manufacturing 10,000 units annually.

Plug will support this project by providing remote monitoring, telephonic field support, overnight parts supply, and customer support. These services are intended to enhance the reliability and performance of the unit and achieve the highest possible customer satisfaction. Scott Wilshire is the Plug Power point of contact for this project. His phone number is 518.782.7700 ex1338, and his email address is scott_wilshire@plugpower.com.

4.0 Principal Investigator(s)

Mr. Samuel Logan, Jr.
President
Logan Energy Corp.
Phone: 770.650.6388 x 101

Fax: 770.650.7317
samlogan@loganenergy.com

Mr. Keith A. Spitznagel
Vice President, Market Engagement
Logan Energy Corp.
Phone: 724.449.4668
FAX: 770.630.7317
kspitznagel@loganenergy.com

5.0 Authorized Negotiator(s)

Mr. Samuel Logan, Jr.
President
Logan Energy Corp.
Phone: 770.650.6388 x 101
Fax: 770.650.7317
samlogan@loganenergy.com

Mr. Keith A. Spitznagel
Vice President, Market Engagement
Logan Energy Corp.
Phone: 724.449.4668
FAX: 770.630.7317
kspitznagel@loganenergy.com

6.0 Past Relevant Performance Information

a) Contract: PC25 Fuel Cell Service and Maintenance Contract #X1237022

Ms. Stephanie Chapman
Merck & Company
Bldg 53 Northside
Linden Ave. Gate
Linden, NJ 07036
(732) 594-1686

Contract: Four-year PC25 PM Services Maintenance Agreement.

In November 2002 Merck & Company issued a four-year contract to LOGAN to provide fuel cell service, maintenance and operational support for one PC25C fuel cell installed at their Rahway, NJ plant. During the contract period the power plant has operated at 94% availability. LOGAN performs the quarterly and annual service prescribed by the UTC, and performs other maintenance as required. The periods of unavailability are chiefly due to persistent inverter problems that seem to be endemic to the Toshiba power conditioning balance of the system. Field modifications and operating adjustments have largely cured the problem. Quarterly service events take 10 hours to complete with the unit under load, and the annual event takes approximately 35 hours with the unit shut down.

b) Contract: Plug Power Service and Maintenance Agreement to support one 5kWe GenSys 5C and one 5kWe GenSys 5P PEM power plant at NAS Patuxant River, MD.

Plug Power

Mr. Scott Wilshire.
968 Albany Shaker Rd.
Latham, NY 12110
(518) 782-7700 ex 1338

LOGAN performed the start-up of both units after Southern Maryland Electric Cooperative completed most of the installation work. The units are located at residential sites at Patuxant River Naval Air Station, VA and operate in standard gird connected/grid independent configurations. Both operate at 4.5kWe and have maintained 98% availability. The units, S/Ns 241 and 242 are two of the very latest GenSys models to reach the field. S/N 242 is Plug Power's first LPG fueled system to go into the field. Both have set a new level of performance expectations for this product, and are indicative of the success of the various test and evaluation programs that have been conducted over the past two years.

c) Contract: A Partners LLC Commercial Fuel Cell Project Design, Installation and 5-year service and maintenance agreement.

Mr. Ron Allison
A Partners LLC
1171 Fulton Mall
Fresno, CA 93721
(559) 233-3262

On April 20, 2004 LOGAN completed the installation of a 600kWe PC25C CHP fuel cell installation in Fresno, CA. The system operating configurations allow for both grid parallel and grid independent energy service. The grid independent system is integrated with a multi unit load sharing electronics package and static switch, which initial development was funded by ERDC CERL in 1999. This is the third fuel cell installation that uses the MULS System. The thermal recovery package installed in the project includes a 100-ton chiller that captures 210 degree F thermal energy supplied by the three fuel cells to cool the first three floors of the host facility. The fuel cells also provide low-grade waste heat at 140 degrees F that furnishes thermal energy to 98 water source heat pumps located throughout the 12-story building during the winter months.

7.0 Host Facility Information

Shaw Air Force Base, located in Sumter, South Carolina, is home to the 20th Fighter Wing. The 20th Fighter Wing can trace its lineage to 28 July 1947, when it began at Shaw Field, South Carolina, as the Ninth Air Force unit.

ASHRAE design temperatures for Shaw Air Force Base are 100° and 24° F. Located at 243 feet above sea level Shaw AFB averages 2,785 Heating Degree Days per year and 1,845 Cooling Degree Days.

The residence of Lieutenant Colonel Jackson is a single family, three bedroom ranch house with attached car port.

Black River Cooperative provides the base with electricity, and South Carolina Pipeline provides its natural gas.

8.0 <u>Fuel Cell Installation</u>

Figure 1 below shows a wide-angle view of the site with the Plug Power fuel cell unit on its pad at Lieutenant Colonel Jackson's residence. Both natural gas and electric services are conveniently located next to the pad. The unit appears to be somewhat obtrusive and a little out of character with a typical residential neighborhood, but this did not cause concern to neighbors. Note the utility transformer in the foreground for relative scale.

The project at Lieutenant Colonel Jackson's residence offered stimulating new challenges and complexities not encountered in previous installations. For example, both the equipment room containing the hot water heater and the closet containing the electrical distribution panel are located within the interior spaces of the house. This necessitated routing electrical conduit and thermal recovering piping through the attic crawl space. It also necessitated the use of seamless water tubing for the thermal piping runs to preclude the risk of overhead plumbing leaks during the year long project. Since the water heater closet was too small to install a companion indirect heater to store fuel cell waste heat as well as other system components, new ideas were needed to integrate the fuel cell with Lieutenant Colonel Jackson's residence.

Figure 2 below shows a new exterior weatherproof equipment shed, behind the Plug Power fuel cell that offered the solution for these installation issues. The small metal building houses the thermal recovery water heater, the reverse osmosis filtration system, the circulating pump and the instrumentation devices that monitor and log fuel cell performance including the Btu meter assembly and the Ultralite data logger.

Figure 2

In Figure 3 below a closer view of the installation shows the electrical panel, meter box and generator disconnect mounted on the fence to the right of the unit. The natural gas service interface is located on the wall behind the fuel cell. Air Force personnel using a base forklift assisted with rigging the unit onto the pad.

Figure 3

Figure 4, below, is a photo of the interior layout of the equipment installed in the metal building adjacent to the fuel cell. The individual components are described below. The thermal recovery system using a Rheem Indirect Heater is designed to capture waste heat from the fuel cell and store it in the form of hot water, which may then be transferred on demand to the residential water heater, located in a central closet within the house. The R/O filtration unit provides deionized water for cell stack hydration, reformate production and cooling. The BTU meter provides a continuous readout of heat transferred into the thermal recovery system. The data logger receives 30-second interval pulse inputs from the natural gas meter, the wattmeter, and the BTU meter, and records the date and time of these events.

Shaw AFB Installation Line Diagram

Lieutenant Colonel Jackson's Residence.

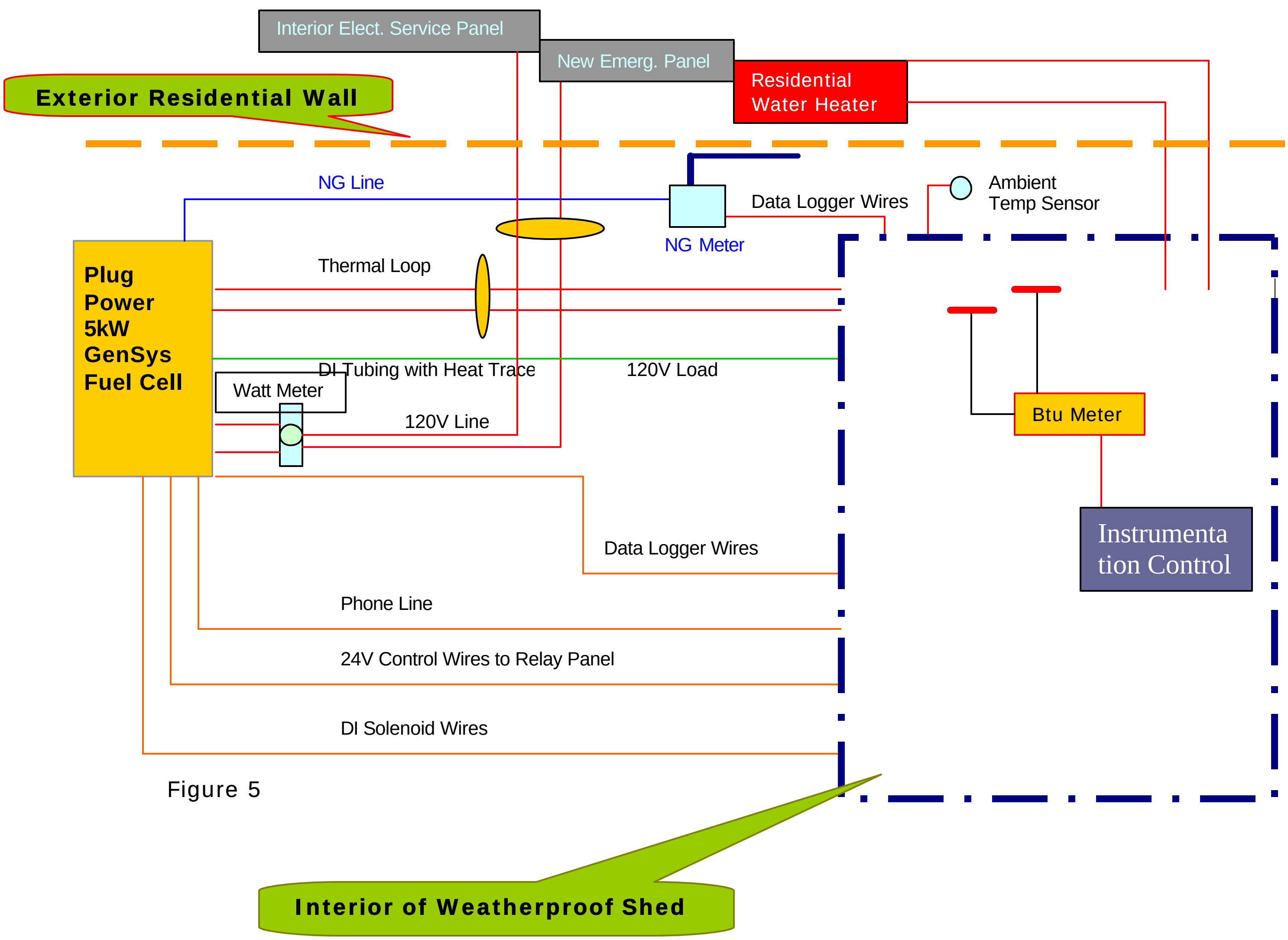

Figure 5

Figure 5, above, diagrams the fuel cell installation with utility interfaces including, power, water and natural gas. The electrical conduit runs to the interior residential load panels from the fuel cell were approximately 60 feet. The Reverse Osmosis/DI water tubing run that provides filtered process water to the power plant is approximately 10 feet distance, and the thermal recovery piping runs between the fuel cell and the new storage tank are also approximately 10 feet.

LOGAN contacted the South Carolina Department of Health and Environmental Control to inquire of the need to apply for an air quality permit to operate the fuel cell. As was the case with the Fort Jackson South Carolina installation, no permit was required. The Public Utilities Squadron provided a digging permit for the site. As the utility distribution wires are the property of Shaw AFB, no grid parallel interconnect permits are required to operate the fuel cell.

The installation tasks were completed and the initial start occurred on April 30, 2003.

9.0 Electrical System

The fuel cell inverter has a power output of 110/120 VAC at 60 Hz, matching the home's power distribution panel with its connected loads at 110/120 VAC. The installation includes both a grid parallel and a grid independent configuration. This is possible because this unit has Plug Power's new MP5 inverter that enables the dual service configuration. The fuel cell provides stand-by power to a new 100amp critical circuit panel that serves plug loads and other convenience outlets in the kitchen.

To do this, LOGAN installed two 120vac wire conductors from the fuel cell to a dual pole meter then to a dual pole service disconnect. The dual pole wattmeter is able to record separately the kW demand on each conductor. From the dual pole service disconnect the conductors split off in two directions. The gird parallel conductor terminates at the main service panel in the residence and the grid independent conductor terminates at the new emergency load panel. Some ordinary kitchen loads supplied by convenience outlets are the circuits, approximately 20 amps of service that were moved to the emergency to simulate the application. The line diagram seen in Figure 5 above, identifies the methods and the individual components that LOGAN used at the site to accomplish this.

10.0 Thermal Recovery System

The Plug Gensys5C fuel cell generates approximately 11,200 Btu of available waste heat while operating at 2.5kWh, the normal set point for this project. The new thermal storage tank installed in the metal building seen in the photo Labeled Figure 4, above, is a 74-gallon Rheem indirect heat coil unit. The heat exchange coils are wrapped around the external shell of the tank. The small circulating pump provides a continuous flow of 135 degree F glycol solution through the tank's coils transferring fuel cell process heat to the tank. Since the Rheem is plumbed directly into the residential hot water heater, it provides hot water as required. Piping runs between the interior tank and the Rheem are approximately 60 feet.

The photo in Figure 4 also indicates the location of an Onicon BTU meter on the thermal recovery system that measures the waste heat transferred to the residence from the fuel cell. The line diagram seen in Figure 5 above, identifies the methods and the individual components that LOGAN used at the site to accomplish this.

The external thermal recovery loop on Plug Power GenSys fuel cells should be designed to meet the following specifications:

- Flow: 0-10 gpm (1-2 gpm will maximize heat reclamation from the fuel cell)
- Pressure: <= 30 psig
- Temperature: (installation specific) with a flow rate of 1-2 gpm, the return temperature to the customer-supplied system will be approximately 140^{o}F
- Available heat:
  - 11,200 BTU/hr @ 2.5kWe
  - 21,900 BTU/hr @ 4.0kWe
  - 27,000 BTU/hr @ 5.0kWe

11.0 Data Acquisition System

Over the course of developing the several sites in the PEM Fuel Cell Demonstration Program, LOGAN has encountered great difficulty in acquiring a dedicated phone line for the fuel cell at every site. In the best case this has delayed commencement of the period of performance by three weeks. At this site, LOGAN encountered a two and one half month delay before the base provided a discrete line to the fuel cell modem. These experiences have taught LOGAN to be very explicit with the host POC at the kick-off meetings about the necessity for providing a dedicated phone line since much of the success of the project is dependent upon reliable communications and data transmission with the unit.

During the period October 2002 to August 2003, LOGAN's field service technicians performed their tasks with the support of a very rudimentary SCADA system developed by Plug Power for communicating with deployed units. This system provided one-way communication from each unit to Plug's customer support center, allowing the unit to call in overnight to download a data package and an operating status report. However, LOGAN realized very quickly that the system was inadequate and unreliable to provide the high level of support needed for this site and the wider-ranging PEM demonstration program. Units providing only partial data or incorrect data most often characterized the inadequacy of the SCADA system. This created uncertainty in troubleshooting and further delay in restoring units to service after discovering they were not operating. On other occasions a unit might fail to call in for a week or more frustrating the normal chain of events leading to a service advisory. While Plug and LOGAN struggled initially with the learning curve experience in developing cooperative service norms, the weakness of the SCADA system became a major source of dissatisfaction with Plug Power. Under the circumstances the only means of determining a unit's actual status was to make a service call to the site. However, the scope of LOGAN's PEM program required a better solution. Finally, in March 2003 an event occurred that gave Plug direct insight into the shortcomings of its SCADA system. After advising of a shutdown at Fort Bragg, Plug sent its own technician to the site because LOGAN's technicians were servicing other units. The technician flew from Albany, New York to Raleigh, North Carolina and then drove out to the site. Upon arriving, the technician discovered that the unit was operating normally. Indeed the SCADA system was not.

This event was an important turning point for the LOGAN/Plug Power relationship and its cooperative efforts in achieving the goals of the PEM Demonstration Program. Six weeks later in early June, six representatives from LOGAN and eight from Plug Power met in Atlanta for two days of forthright discussions. The meeting focused on short-term methods and longer term solutions to improve remote PEM fuel cell performance. Most significantly Plug determined that it would institute immediate software changes and upgrades to insure the accuracy of fuel cell data communications. Plug also promised to initiate a design change to its SCADA system that would permit bi-directional remote communications with the fuel cell controller. More importantly Plug promised that LOGAN's technicians would be able to remotely troubleshoot, change set points and attempt restarts under some circumstances. Lastly they also promised that they would publish a daily status report covering all of LOGAN's units. By early August Plug began sending daily status reports, and by mid September Plug shipped LOGAN's technician's new control software that permits remote diagnostics, monitoring, troubleshooting, and restart capabilities. Since the introduction of this new service capability along with the adoption of improved service techniques to go with it, fleet performance, availability and operating costs have begun to show positive new trends.

An Ultralite Logger pictured above in <u>Figure 4</u>, above, records and stores inputs from the wattmeter, gas meter, Btu meter and an ambient temperature probe all located within the metal building. A phone connection to the unit permits remote data retrieval.

12.0 Fuel Supply System

Natural gas service for the fuel cell was conveniently located next to the pad. A new natural gas meter, illustrated in Figure 5, above, provides an independent verification of fuel flow, and a regulator at the fuel cell gas inlet maintains the correct operating pressure. A pulse signal is sent from the natural gas meter to the data logger.

The Plug Power PEM fuel cell natural gas requirements are:

- Must be >90% methane
- No greater than 15 ppm sulfur on a yearly average basis
- Supply Pressure: 4” to 11” water column
- Maximum flow rate: 105,000 btu/hr
- Nominal flow rate: 72,700 btu/hr

13.0 Program Costs

Installation Costs – Estimated vs. Actual

Shaw Air Force Base

Project Utility Rates					
1) Water (per 1,000 gallons)		$0.64			
2) Utility (per KWH)		$0.0610			
3) Natural Gas (per MCF)		$9.50			
First Cost				**Estimated**	**Actual**
Plug Power 5 kW GenSys5C				$ 65,000.00	$ 65,000.00
Shipping				$ 1,800.00	$ 600.00
Installation electrical				$ 4,200.00	$ 2,121.00
Installation mechanical & thermal				$ 5,000.00	$ 5,000.00
Watt Meter, Instrumentation, Web Package				$ 3,150.00	$ 3,429.00
Site Prep, labor materials				$ 925.00	$ 494.00
Technical Supervision/Start-up				$ 8,500.00	$ 9,720.00
Total				**$ 88,575.00**	**$ 86,364.00**
Assume Five Year Simple Payback				$ 17,715.00	$ 17,272.80
Forcast Operating Expenses	Volume	$/Hr		$/ Yr	
Natural Gas Mcf/ hr @ 2.5kW	0.0328	$ 0.31		$ 2,459.50	
Water Gallons per Year	14,016			$ 8.97	
Total Annual Operating Cost					$ 2,468.47
Economic Summary					
Forcast Annual kWH		19710			
Annual Cost of Operating Power Plant		$ 0.125	kWH		
Est Annual Thermal Recovery Credit		$ (0.028)	kWH		
Project Net Operating Cost		$ 0.097	kWH		
Displaced Utility cost		$ 0.061	kWH		
Energy Savings (Increase)		($0.036)	kWH		
Annual Energy Savings (Increase)		($716.77)			

Explanation of Calculations:

Actual First Cost Total is a *sum* of all the listed first cost components.

Assumed Five Year Simple Payback is the Estimated First Cost Total *divided by* 5 years.

Forecast Operating Expenses:

Natural gas usage in a fuel cell system set at 2.5 kW will consume 0.033 Mcf per hour. The cost per hour is 0.033 Mcf per hour *x* the cost of natural gas to Shaw at $9.50/MCF. The forecast cost per year at $2459.50 is the gas cost per hour of $0.31 *x* 8760 hours per year *x* 0.9. The 0.9 represents 90% availability.

Natural gas fuel cell systems set at 2.5 kW will consume 1.6 gallons of water per hour through the DI panel. The total volume of water consumed at 14,016 gallons per year is 1.6 gph *x* 8760 hours per year times 90% availability. The cost per year at $8.97 is 14,016 gph *x* cost of water to Shaw at $0.64 per 1000 gallons times availability.

The Total Annual Operating Cost, $2468.47 is the *sum of* the cost per year for the natural gas and the cost per year for the water consumption.

Economic Summary:

The Forecast Annual kWh at 19,710 kWh is the product of 2.5 kW set point for the fuel cell system *x* 8760 hours per year *x* 0.9. The 0.9 is for 90% availability.

The Annual Cost of Operating the Power Plant of $0.125 per kWH equals the Total Operating Cost of $2468.47 *divided by* the forecast annual kWh at 19,710 kWh.

The Forecast Annual kWh at 19,710 kWh is the product of 2.5 kW set point for the fuel cell system *x* 8760 hours per year *x* 0.9. The 0.9 is for 90% availability.

The Credit for Annual Thermal Recovery of $0.018/kWH equals 7800 BTU per hour thermal recovery at 2.5 kW *divided* by 3414BTU/kwH *multiplied* .20 recovery factor, *multiplied* by $0.0610/kWh. As a credit to the cost summary, the value is expressed as a negative number.

The Project Net Operating Cost is the *sum* of the Annual Cost of Operating the Power Plant *plus* the Credit Annual Thermal Recovery.

The Displaced Utility Cost is the kWh cost of electricity to the site.

The Project Net Operating Cost is the *sum* of the Annual Cost of Operating the Power Plant *plus* the Credit Annual Thermal Recovery.

The Displaced Utility Cost is the cost of utility service paid by Shaw AFB per kWh.

Energy Savings (increase) equals the Displaced Utility Cost *minus* the Project Net Operating Cost.

Annual Energy Savings (increase) equals the Energy Savings *x* the Forecast Annual kWh

14.0 Milestones/Improvements

The GenSys Residential PEM fuel cell at Shaw Air Force Base was placed on its pad in March, 2003. The first successful eight hour run of the fuel cell took place on April 30, 2003. This power plant experienced ten unplanned shutdowns during the 12 month demonstration. The fuel cell had only one planned shutdown during the demonstration because most preventative maintenance (PM) was performed during the unplanned shutdowns. The fuel cell demonstration was successfully completed on May 17, 2004

Over the course of the 12 month demonstration the fuel cell was available 90.2% of the time. This is a significant improvement over previous demonstrations. This improvement can be attributed to improvements in the fuel cell design by Plug Power and improved maintenance expertise on the part of LOGANEnergy field technicians.

15.0 Decommissioning/Removal/Site Restoration

The Demonstration program for unit 191 ended on May 17, 2004. Per the Colonel's request, this unit was not disassembled until after June 23, 2004. The stack from this unit was removed and sent to the Plug Power unit (SU190) at North Carolina A&T University. The balance of this unit was sent back to Plug Power.

16.0 Additional Research/Analysis

On May 18, 2004 a Harmonic Meter was used to measure the harmonics of the existing electrical system at the Jackson residence both with the fuel cell connected and with the fuel cell disconnected. The measurements from this test are attached in Appendix 3. (Harmonic readings are proprietary).

17.0 Conclusions/Summary

In general terms, the Shaw Air Force Base project did not encounter any major logistical obstacles or other events that patience and cooperation among the stakeholders did not eventually solve. The test period concluded with a total 8284 fuel cell load hours, 20,121 kWh of electricity generated and achieved an overall availability of 90%.

Problems with obtaining telephone lines continue to be an issue. Although the fuel cell was commissioned on April 30, the phone line was not available until June 12. After phone service was installed there were numerous instances where the fuel cell was unable to call out. Some of these communication issues were caused by the modem in the fuel cell and some by the SARC controller.

On August 26, 2003 the Grid Independent circuit of the fuel cell was given a “real world” test when Shaw Air Force Base experienced an electric utility power failure. The Jackson house, including their refrigerator, television and computer continued to operate on fuel cell power when the neighbors lost power.

The lesson learned at this site from the installation experience and responding to the 10 unplanned shutdowns will transfer well to other projects served by LOGAN, Plug Power and CERL. In addition, the experience has been a forceful contribution to greater fuel cell awareness on the base and within the local community, as well as the broader objectives of the fuel cell industry and product commercialization.

Appendix

1) Monthly Performance Data
2) Work Logs
3) Installation Acceptance Test
4) Harmonics Test